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Mine Test of a Cryogenic Refuge Alternative Supply System (CryoRASS)

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18 February 2015
SME Conference, Denver

This effort is completed as part of CDC Inter-Agency Agreement (IAA/SAA):-
CDC Agreement No: 12FED1213259, NASA SAA No: KCA-4357

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Cryogenic Refuge Alternative Supply System

NASA

John F. Kennedy Space Center

Abstract

This test demonstrated the feasibility of a cryogenic air supplied refuge alternative conducted in a mine.

Why cryogenic air?

- Provide a new technology method for air storage
- Store more air in less space to reduce size & weight
- Store air at lower pressure to improve safety
- Provide <u>heat stress relief</u> to improve comfort & survivability – reduce temperature and humidity

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Basic Design considerations

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- Store 96 hours of air supply in liquid form.
  - Use 2 x 425 liter + 300 liter dewars for a 23 man chamber
- Preserve quantity and composition of liquid air until use.
  - Use cryocooler to overcome heat leak during long term storage
    - Assume electrical power until emergency
    - Assume no electrical power during emergency
- Simple activation by first miner to enter (1 pull)
- Provide air at 5X oxygen quantity (1.32 ft^3/hr/person)
- Provide cooling for heat stress relief
- Provide dehumidification for heat stress relief
- Provide air circulation
- Provide partial CO_2 flushing

How much liquid air?

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- NIOSH requirement = 1.32 ft^3 oxygen/ hour/person
  - X5 = 6.6 ft^3/hr since O_2 is ~20% component of air
  - for 23 miners = 152 ft^3/hr
  - for 96 hours = 14,575 ft^3 (total)
  - gaseous flow rate = 4300 liters/hr = 72 liters/minute (minimum)

- Volumetric expansion ratio for liquid to gaseous air = 728 : 1
  - total liquid required: 14,575 ft^3 (gas) = 20 ft^3 (liquid) or 566 liters
  - → minimum flow to air handler = 72 liters/minute (gaseous)
    - to provide maximum duration (165 hr)

- CryoRASS storage for this test = 425 CryoRASS + 425 CryoASFS + 300 ZL
  - For 96 hours, can flow (1150 x 728) = 837,200 liters gaseous
  - → maximum flow rate (for 96 hr) = 145 liters/minute (choose 140 l/min)
    - to provide maximum cooling and dehumidifaction

CryoRASS basic schematic

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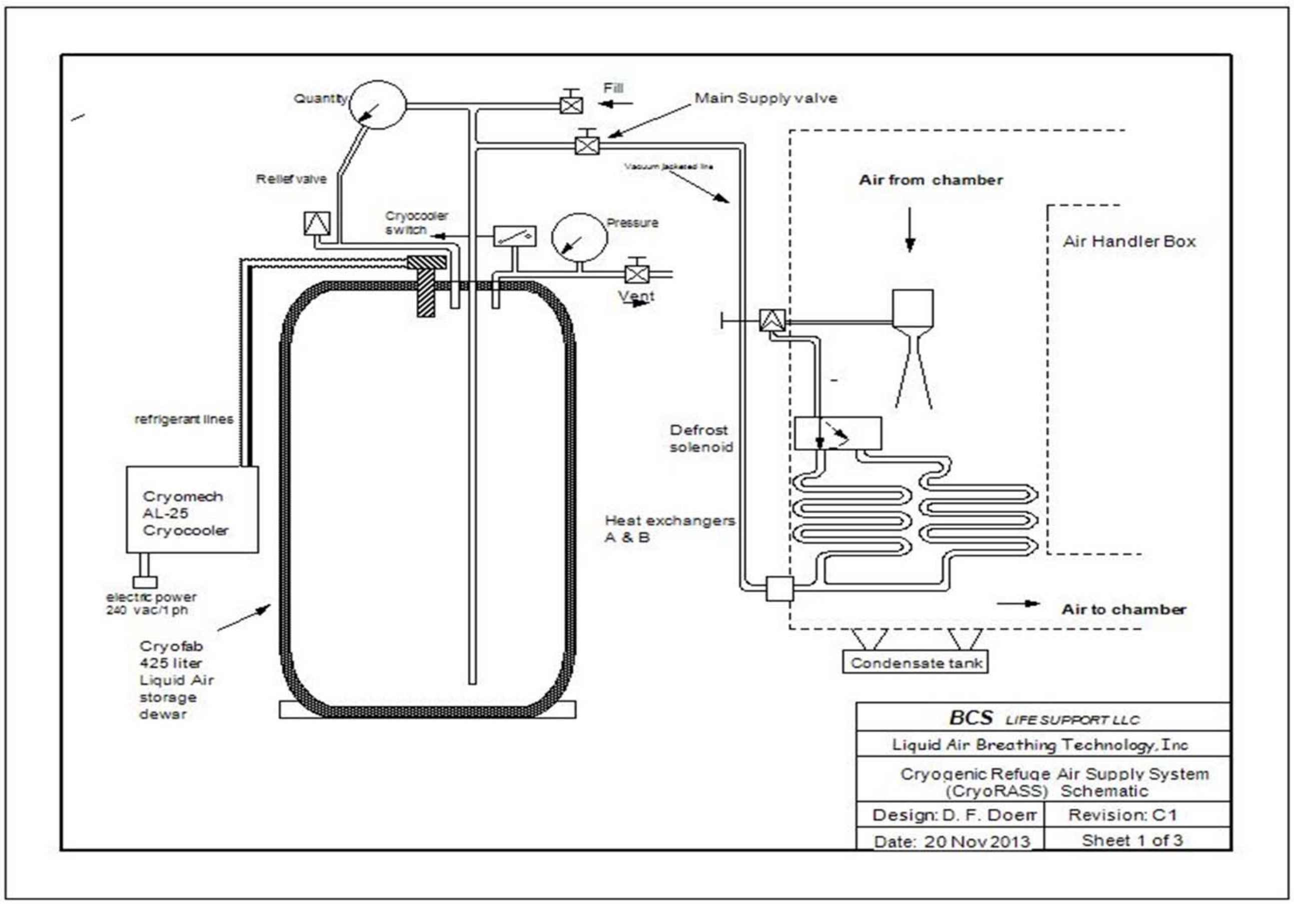

CryoRASS Prototype 1

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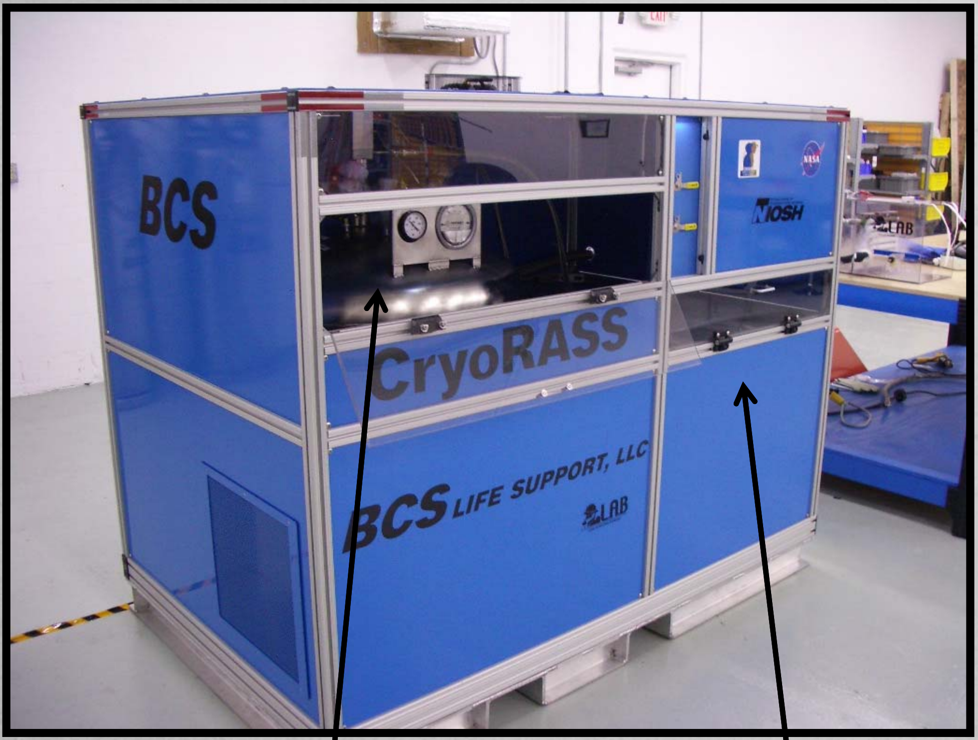

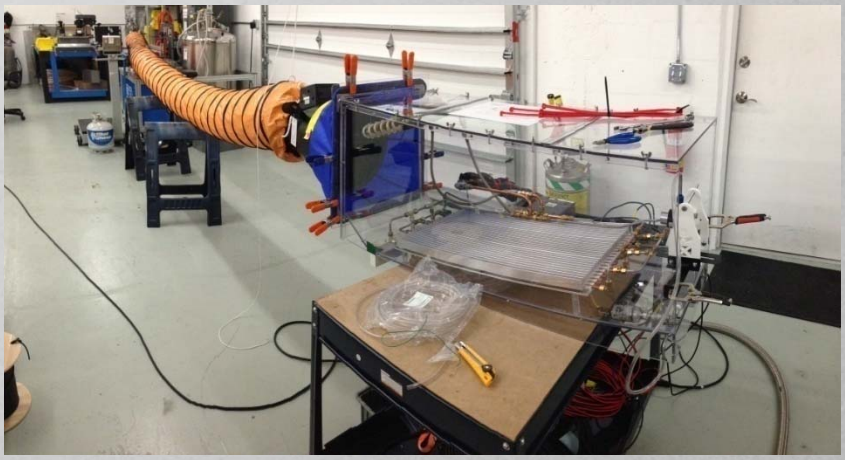

Air Handler box
w/ duct attached

Cryocooler behind panel

Liquid Air 425 liter dewar

Test plan for CryoRASS in Experimental Mine

- Commercially available, inflatable Refuge chamber (23 man)
- Instrument for temperatures, pressure, humidity
- Use “barrel person” simulators to generate heat and water vapor
  - Add 494 BTU per person
  - Add 1.3 liters water per person/hr
- Conduct 96 (continuous) hour test
- Isolate chamber in cross-cut with insulated walls
- Digitally record all data
- Test conducted by Pittsburgh OMSHR personnel
- BCS/LABTech support on site for operation of CryoRASS

Instrumentation diagram

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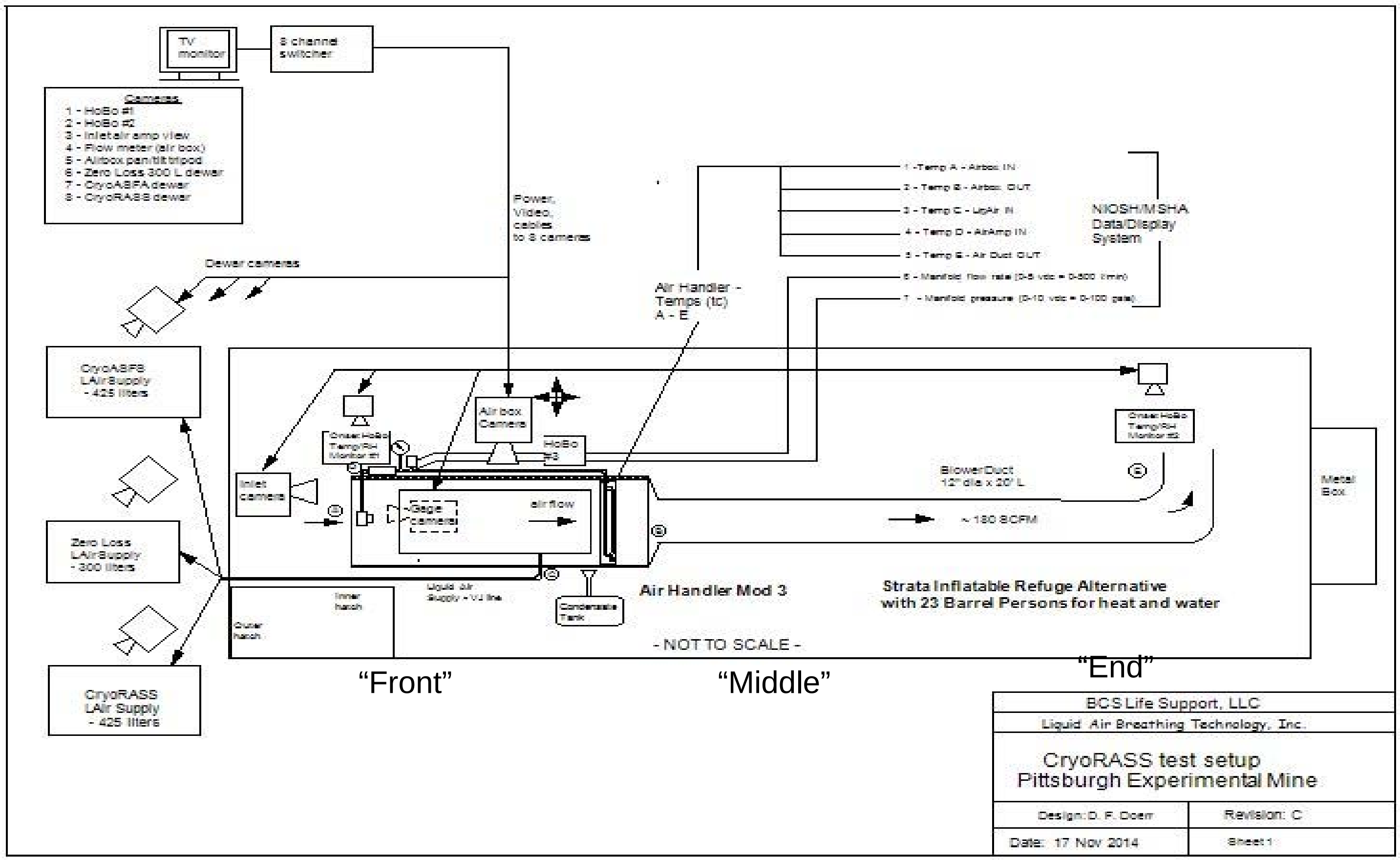

Refuge chamber interior

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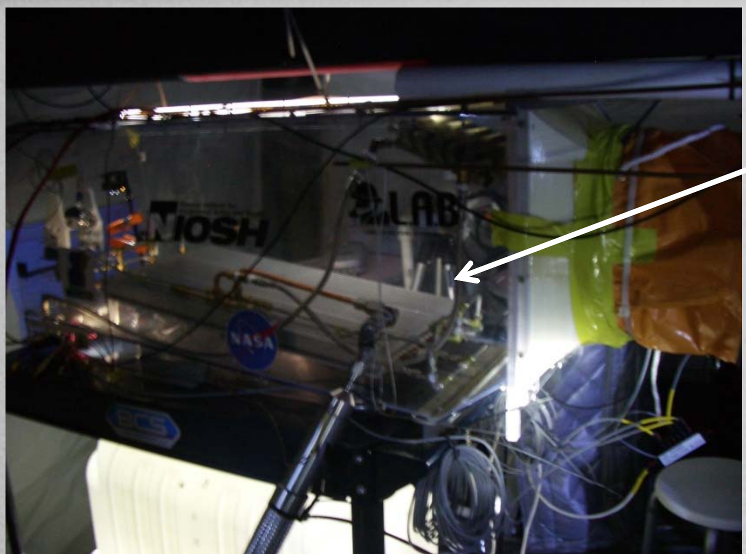
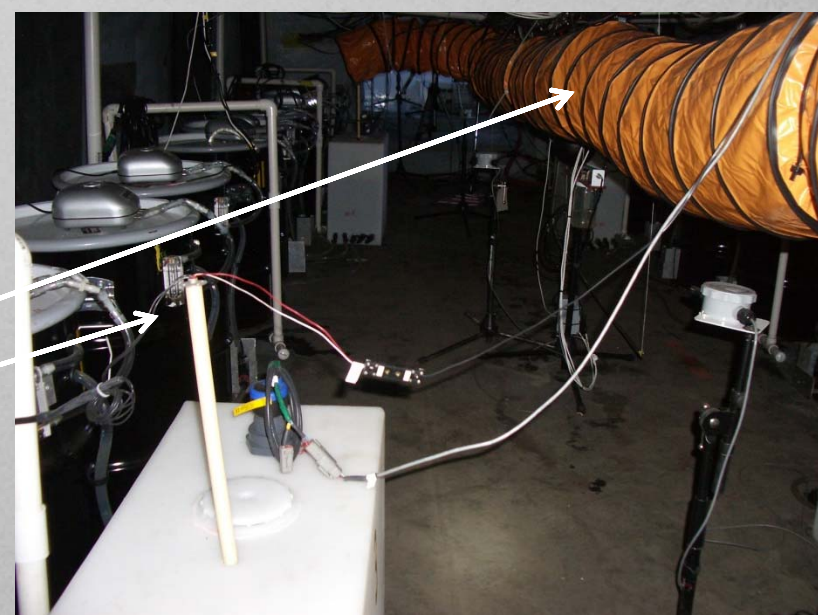


Air Handler Box
- liquid air input from bottom
- cold plates above

Air duct from air handler (right)
Note “barrel persons” (left)



Testing of CryoRASS

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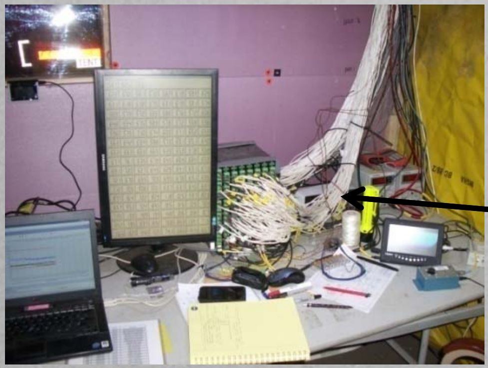
CryoRASS connected to 23 man Inflatable chamber



Control room with test instrumentation & video monitoring

Temperature Data with CryoRASS

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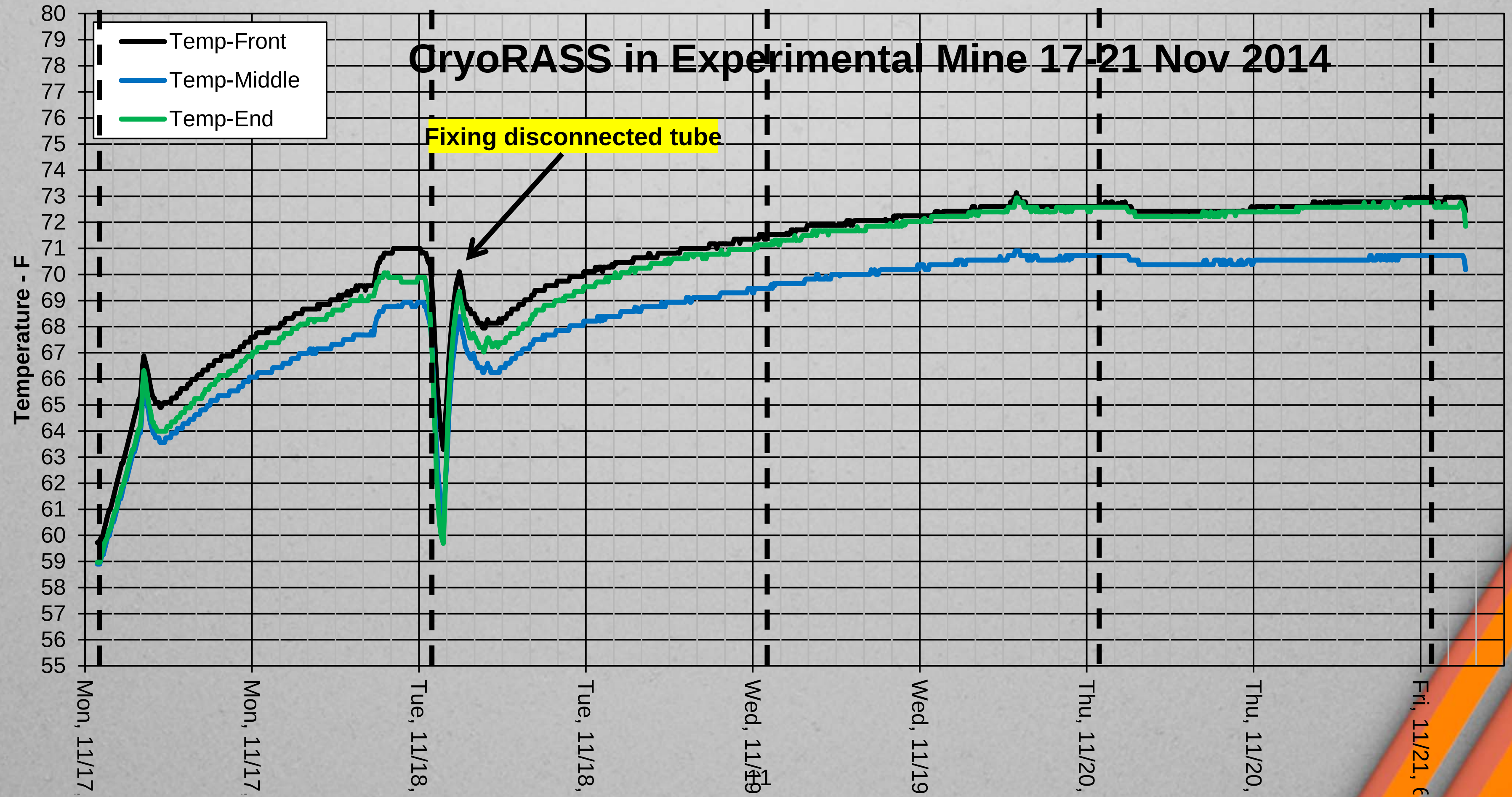

Temperature Data - Baseline

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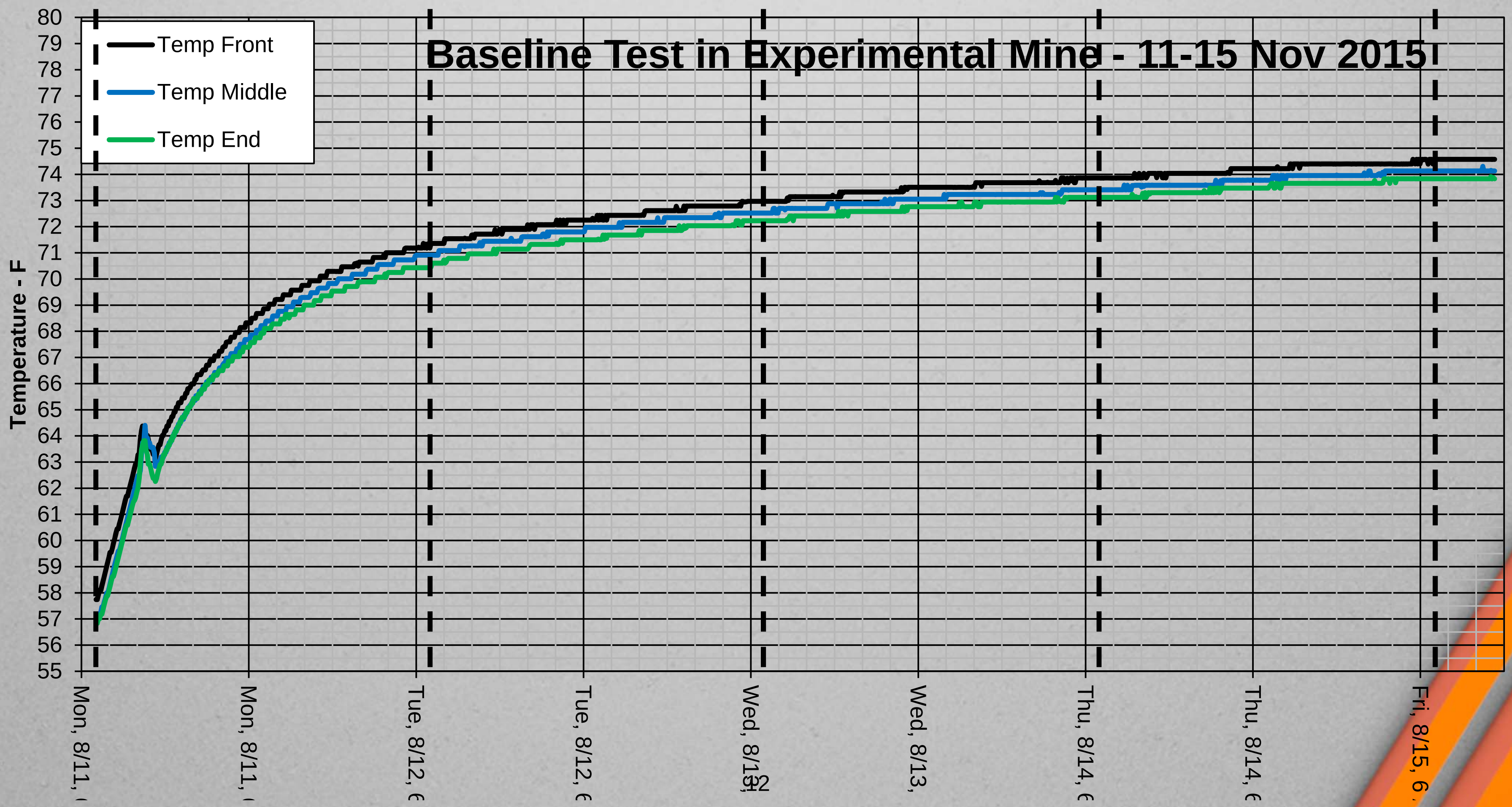

Humidity Data with CryoRASS

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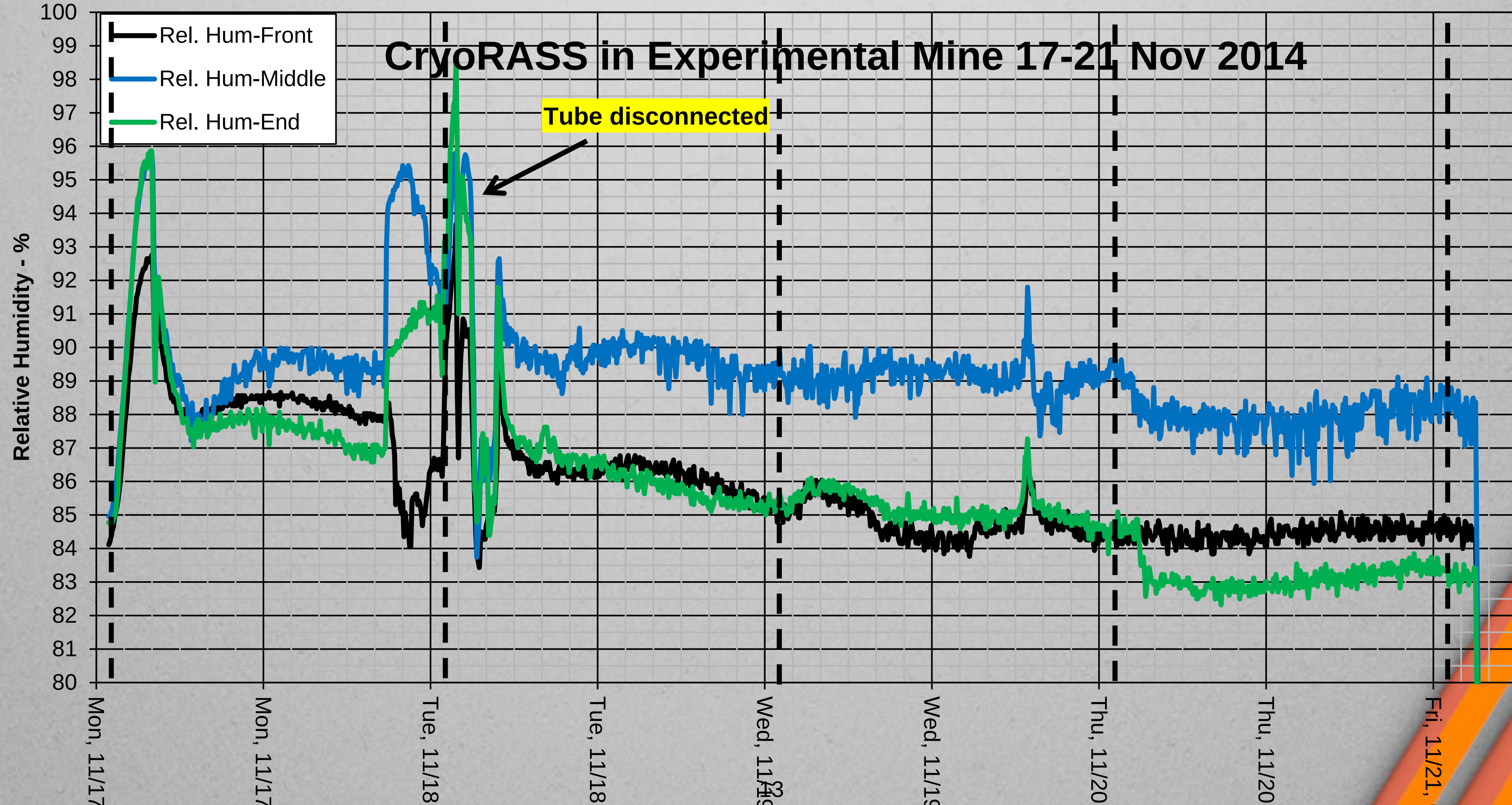

Humidity Data - Baseline

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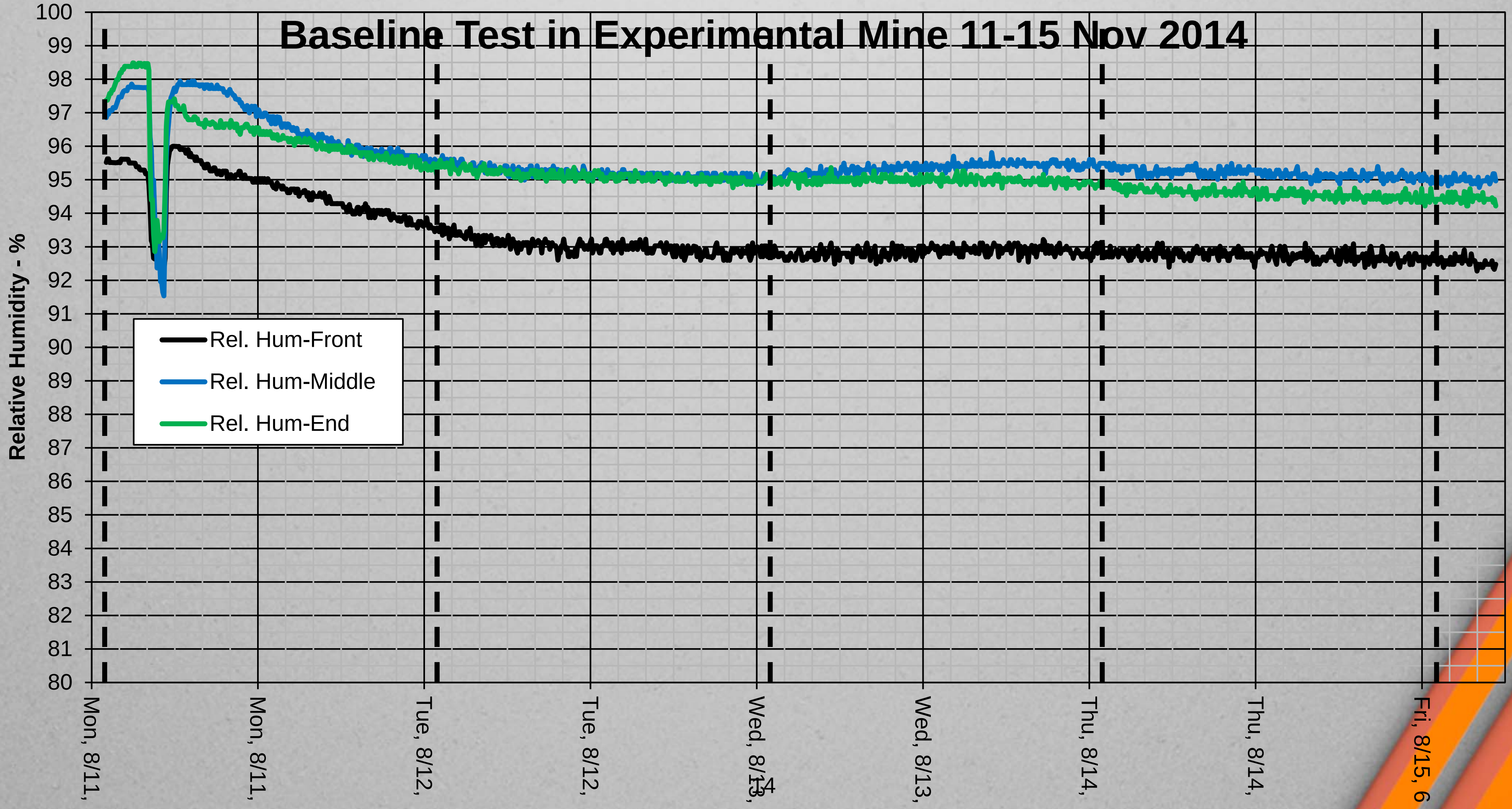

Entry Observations

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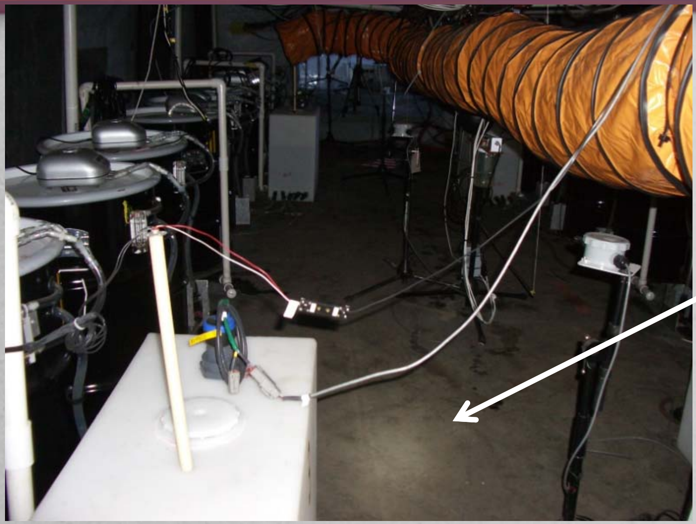
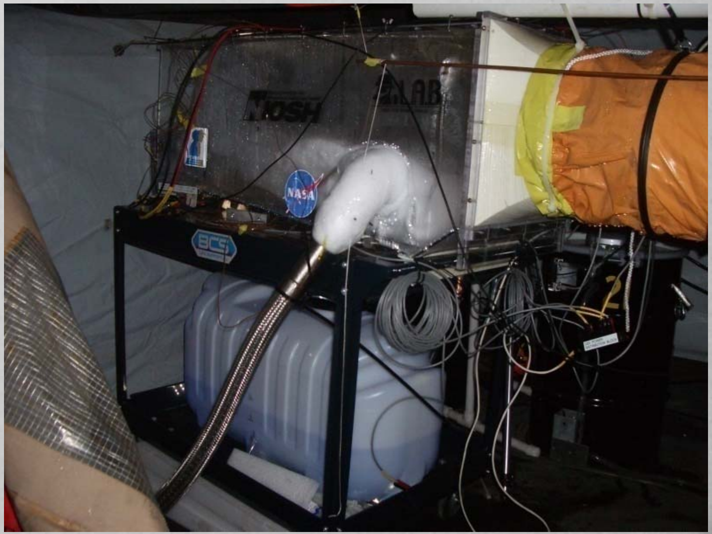


Note dry
floor in “Middle” and “End”



Air handler, cold plate
and condensate tank
In “Front”

Partially dry
floor in “Front”

Test Results Summary

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- Actual (dry bulb) temperatures were marginally lower (~2.2° F)

- Considerable humidity removed (~ 11 gallons),
    - RH down to 85%
    - RH down to 76% at duct outlet

- Apparent temperature reduction:
    - Baseline: 74°F, 94% RH = 83.3°F Apparent
    - CryoRASS: 72.0°F, 85.5% RH = 78.6°F Apparent
    - <u>**Overall apparent temperature reduction: 5°F**</u>

- No effort was made to model or control CO_2

Conclusion

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- This test proved concept feasibility and prototype design
- CryoRASS system creates refuge circulation (~ 150 SCFM) at duct
- Temperature and humidity reduced
- Heat stress relief provided (5°F apparent temp reduction)
- Safety enhanced (low pressure air source)
- Air source space & weight requirement decreased
- Although not specifically tested here, increased airflow will purge CO_2, reducing the CO_2 levels in the chamber, thus reducing the need for CO_2 scrubbing. Since CO_2 scrubbing is a significant exothermic reaction, any reduction in the CO_2 concentration will result in additional heat savings.

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What's next?

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- Add second cold plate to air handler box to condense more water & reduce frosting
- Prototype 2 CryoRASS (currently in work)
    - Change to1000 liter horizontal dewar (low seam mines)
    - Ruggedize construction to comply with MSHA
    - Larger cryocooler
- Design to fit existing inflatable and rigid chambers
- Improve air duct design to protect against flow restrictions and improve total airflow
- Develop user selectable airflow valve
- Add air curtain at entry point for purging during ingress

Questions?

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